Gasification of Alberta Coals

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal and conventional energy resources, as well as energy conservation and renewable energy. Program administration is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy.

In recognition of the importance of coal to Alberta's economy, the Alberta Office of Coal Research and Technology was established in 1984 within Alberta Energy and Natural Resources (now Alberta Energy). Its primary purpose is to encourage the development and application of new technologies related to Alberta coals. The Office provides funding contributions to research and development projects in industry, academic institutions and other research establishments and monitors their progress in an overall program of improving the production, transportation and marketability of Alberta coals.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page 10.

Gasification of Alberta Coals

In 1987, a consortium[1] of sponsors, headed by TransAlta Utilities Corporation of Calgary, funded an investigation of coal gasification technologies and applications, as well as the potential of using Alberta coal in existing or emerging systems.

The study concluded that Integrated Gasification Combined Cycle (IGCC) systems now under development are demonstrating several advantages over current coal-fired thermal technology for electricity generation. In particular, IGCC is considered the frontrunner of various proposed "clean coal" technologies intended to produce substantially lower concentrations of air emissions than conventional thermal, electricity-generating systems. Although experience with large-scale IGCC systems is limited, all indications suggest that they produce considerably less sulphur oxide and nitrogen oxide emissions than do conventional coal combustion facilities. Particulates are also reduced significantly in comparison with conventional thermal plants. In addition, IGCC plants have higher thermal efficiencies than coal combustion plants.

For these reasons, it was recommended that Alberta coal producers and researchers should become actively involved in IGCC developments. A technology transfer booklet, Fluidized Gasification of Western Canadian Coals, was produced and distributed by the Alberta Office of Coal Research and Technology to encourage participation in a joint industry/government research program. Subsequently, the Canadian Coal Gasification Technical Committee[2] was formed to oversee and fund coal gasification projects comprising a multi-year research program. The objectives of this program are:

- to design and build by 1994 a 100 MW (electrical) prototype IGCC plant in Canada;
- to establish and standardize coal gasification testing methods for Canadian laboratories; and
- to facilitate performance evaluations of Canadian coals in various coal gasification technologies.

The program has been divided into five major elements. They are:

- Technology assessment;
- Coal characterization;
- Exploratory experimentation;
- Engineering systems design; and
- Applications research.

Projects associated with these elements are to focus on each of the major steps involved in gasification, from preparing coal as feedstock to emission control.

Projects which have evolved are described here. All of them received financial assistance from the Alberta/Canada Energy Resources Research Fund (A/CERRF), but some details are regarded as confidential. The availability of information, in addition to what is reported here, is at the discretion of the project performers listed on page 10.

[1]The consortium comprised: TransAlta Utilities Corporation (with Monenco Consultants Limited as the principal subcontractor), Alberta Power Limited, Luscar Ltd., Saskatchewan Power Corporation, Atlantic Coal Institute and the Alberta Office of Coal Research and Technology.

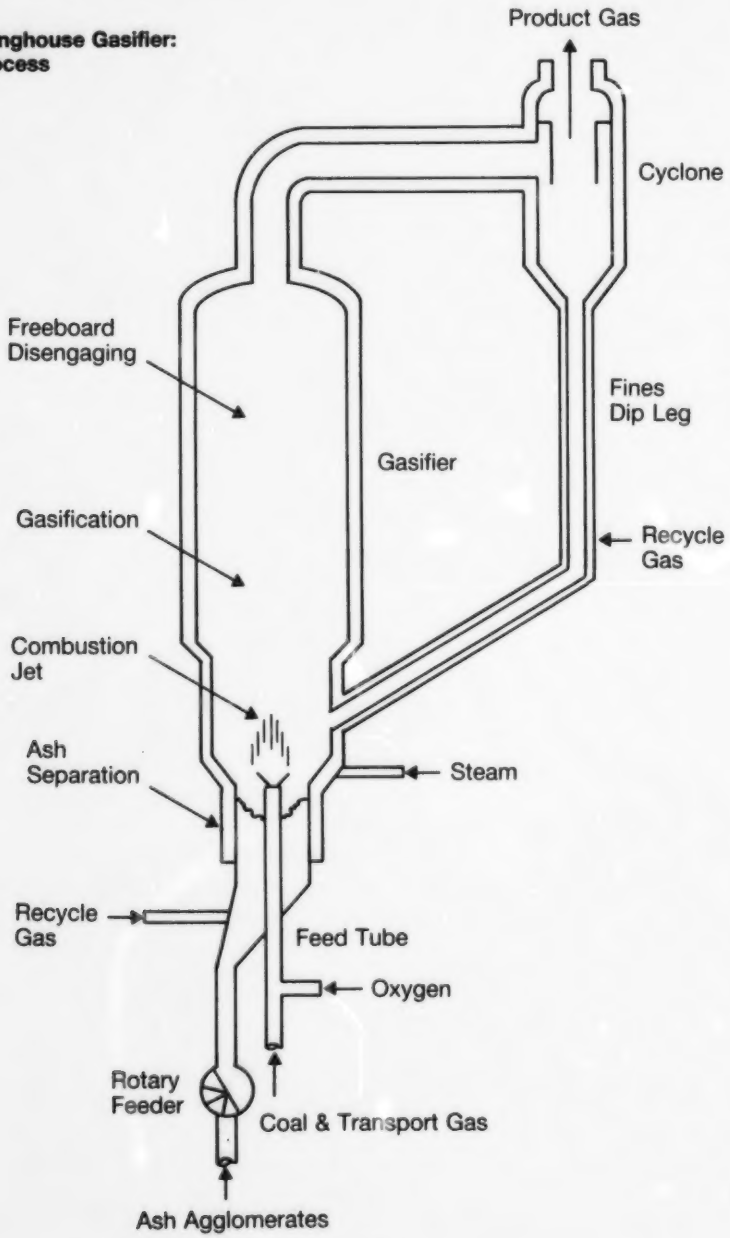
[2]As of February 1989, participants in the Canadian Coal Gasification Technical Committee were: TransAlta Utilities Corporation, Saskatchewan Power Corporation, Shawinigan Integ Inc., Shell Canada Limited, Westar Mining Ltd., Monenco Consultants Limited, Luscar Ltd., Alberta Power Limited, Unocal Canada Limited, Esso Resources Canada Limited, Gulf Canada Resources Limited, Nova Scotia Department of Mines and Energy, Saskatchewan Department of Energy and Mines, Canada Centre for Mineral and Energy Technology, and the Alberta Office of Coal Research and Technology, assisted by the Alberta Research Council.

Gasification Research at Alberta Research Council

Scientists at the Alberta Research Council (ARC) have been studying coal combustion for several years. As a result, they have developed combustion test instruments and methods, and have begun to acquire a combustion data base for Alberta coals.

As an extension of this work, several coal gasification projects were undertaken at the Alberta Research Council to help establish this agency as a focal point for gasification research in Alberta.

Kellogg-Rust-Westinghouse Gasifier: A Fluidized Bed Process



(Source: *Gasification of Western Canadian Coals*, TransAlta Utilities Corporation, January 1987)

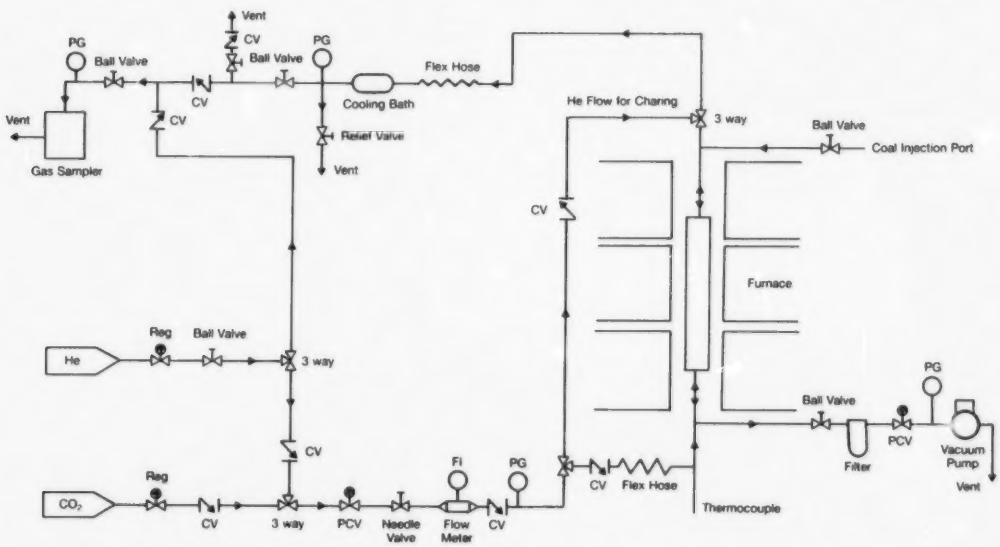
To introduce staff to emerging technologies and recent developments, gasification facilities were visited in The Netherlands, the Federal Republic of Germany, the United Kingdom, Pennsylvania and California. At these locations, ARC staff observed the process developed by Royal Dutch Shell, Krupp-Koppers' PRENFLO, the HT Winkler process, the processes of British Gas Corporation/Lurgi, KRW, and Texaco's Cool Water process. Also, visits were made to gasification laboratories at the University of British Columbia and overseas, and seminars were attended in the U.S.

Gasification Testing Facilities

Subsequently, laboratory-scale gasification testing facilities (coal feed rate less than 1 kg/h) were established at ARC to permit evaluation of Alberta coals under gasification conditions. Equipment and procedures were developed to perform high heating rate (up to 1000°C/s) coal gasification studies.

In co-operation with the University of British Columbia, studies involving a fluidized-bed reactor were undertaken, and a similar arrangement was made with the Canada Centre for Mineral and Energy Technology (CANMET) for access to an entrained-flow reactor. A powerful Sun 4/260 microcomputer was acquired, and software was purchased and developed to facilitate single particle and equilibrium modelling studies. With the provision of these facilities, ARC scientists can conduct coal characterization studies in co-operation with other coal gasification researchers across the full range of commercial or near-commercial technologies and provide a valuable support service for other Alberta gasification investigations.

Fixed Bed Coal Gasification Flowsheet



(Source: *Gasification Kinetics of Alberta Coals Using a High Pressure Fixed Bed Reactor*, Kovacik, G., A.K. Chambers and B. Özum, Alberta Research Council, 1988)

Gasification Properties of Alberta Coals

If Alberta utility companies are to make well-informed choices for their next generation of power plants and if Alberta coal producers are to market their coals effectively elsewhere in the world, it is essential that several coal properties be evaluated to determine the acceptability of coals in any particular gasification system. These properties include: reactivity under pertinent test conditions; particle size distribution before and during reaction; ash slagging properties; and ash volatility.

Consequently, the process of testing Alberta coals for their gasification characteristics was begun at ARC by using a thermogravimetric analyser (TGA) to measure gasification rates of coal chars. Measurements were made on subbituminous, low-volatile bituminous and high-volatile bituminous coals from Alberta and a well-characterized coal from Illinois. Gasification experiments were carried out at approximately 700°C to 900°C under carbon dioxide at atmospheric pressure. The effects of particle size, heating rate and gasification temperature on char reactivity were investigated.

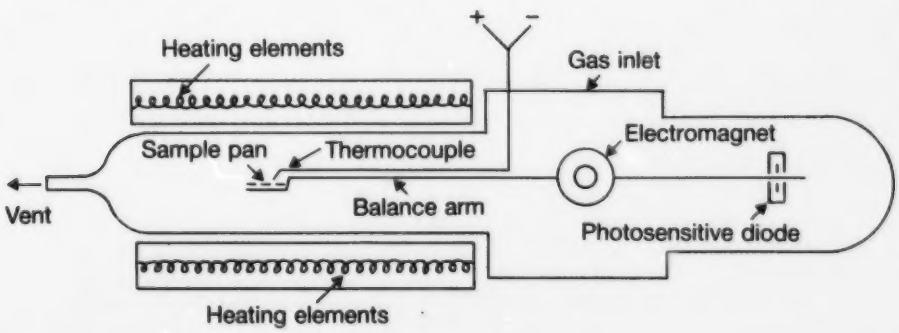
It was found that heating rate influenced the results for every char. This was especially true for highly reactive coal. Also, reactivity increased with decreasing coal rank, although the Alberta high-volatile bituminous coal was more reactive than the Illinois bituminous coal. As well, it was found that reactivity increased as the char particle size decreased.

It was concluded that Alberta coals gasify well at high heating rates and are well-suited for entrained-bed gasification technology. Also, the TGA reactivity test was shown to be a simple technique for comparing coal gasification reactivity and estimating the time required for gasification of a given particle size range and temperature.

An attempt was made to understand the gasification kinetics of these coals. Two theories (the volume reaction model and the grain model) were applied to explain the structural changes that occurred when Alberta coals were converted to chars. Both theories could be used to establish correlations with the TGA data for the high-volatile bituminous and subbituminous Alberta coals. Also, a boundary layer mathematical model was developed for the combustion and gasification of a single char particle. Experimental data obtained when particles were combusted in an entrained-flow reactor were used to validate the numerical model.

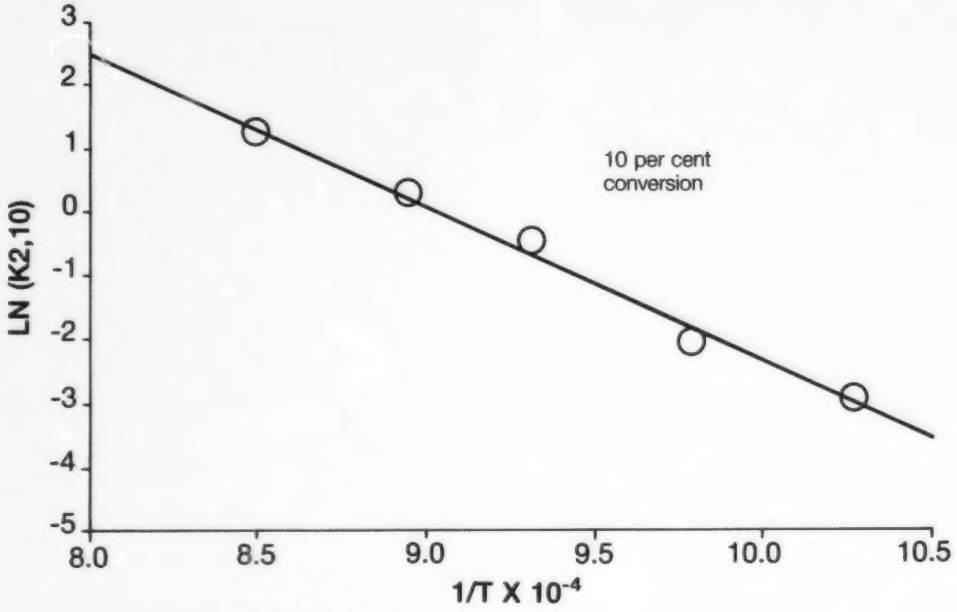
Included in this project was a coal characterization study involving analysis and testing of coals from British Columbia, Alberta, Saskatchewan and Nova Scotia to enable predictions of coal behaviour under conditions encountered in various gasification reactors. Approximately 30 parameters were studied to establish basic composition and gasification characteristics of 20 coals. Testing was carried out by the Alberta Research Council and the Geological Survey of Canada, under the leadership of CANMET.

Schematic of Thermogravimetric Analyser (TGA)



(Source: *Study of Fundamental Gasification Properties of Alberta Coals*, Kovacik, G., B. Ozum, D. Ungarian and A.K. Chambers, Alberta Research Council, 1988)

Arrhenius Plot for Subbituminous Char Using the Grain Model with 75-105 μm Particle Size



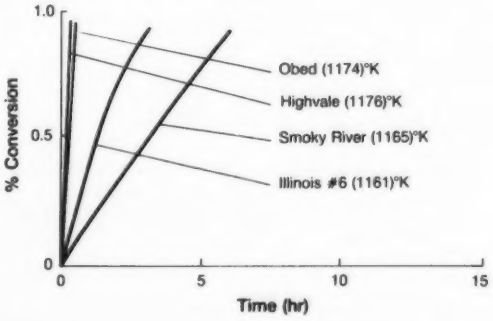
(Source: *Study of Fundamental Gasification Properties of Alberta Coals*, Kovacik, G., B. Ozum, D. Ungarian and A.K. Chambers, Alberta Research Council, 1988)

Evaluation of Alberta Coals in Gasification Technologies

Five coals supplied by five Alberta coal producers were evaluated for their suitability and performance in Texaco, British Gas and Shell gasifier technologies. All of these technologies use oxygen as the gasification medium and they employ slagging ash removal. Also, they are candidates for commercial-scale Integrated Gasification Combined Cycle plants. While both the Texaco and Shell processes are examples of entrained-flow systems, the British Gas process is representative of a fixed-bed gasifier.

Within the scope of the project, each company evaluated the coals, but actual gasification experiments were not performed. Therefore, these evaluations were regarded as initial screening tests only. For coals judged to be suitable, the gasifier companies supplied information on predicted mass and energy balances and a gasifier product gas composition.

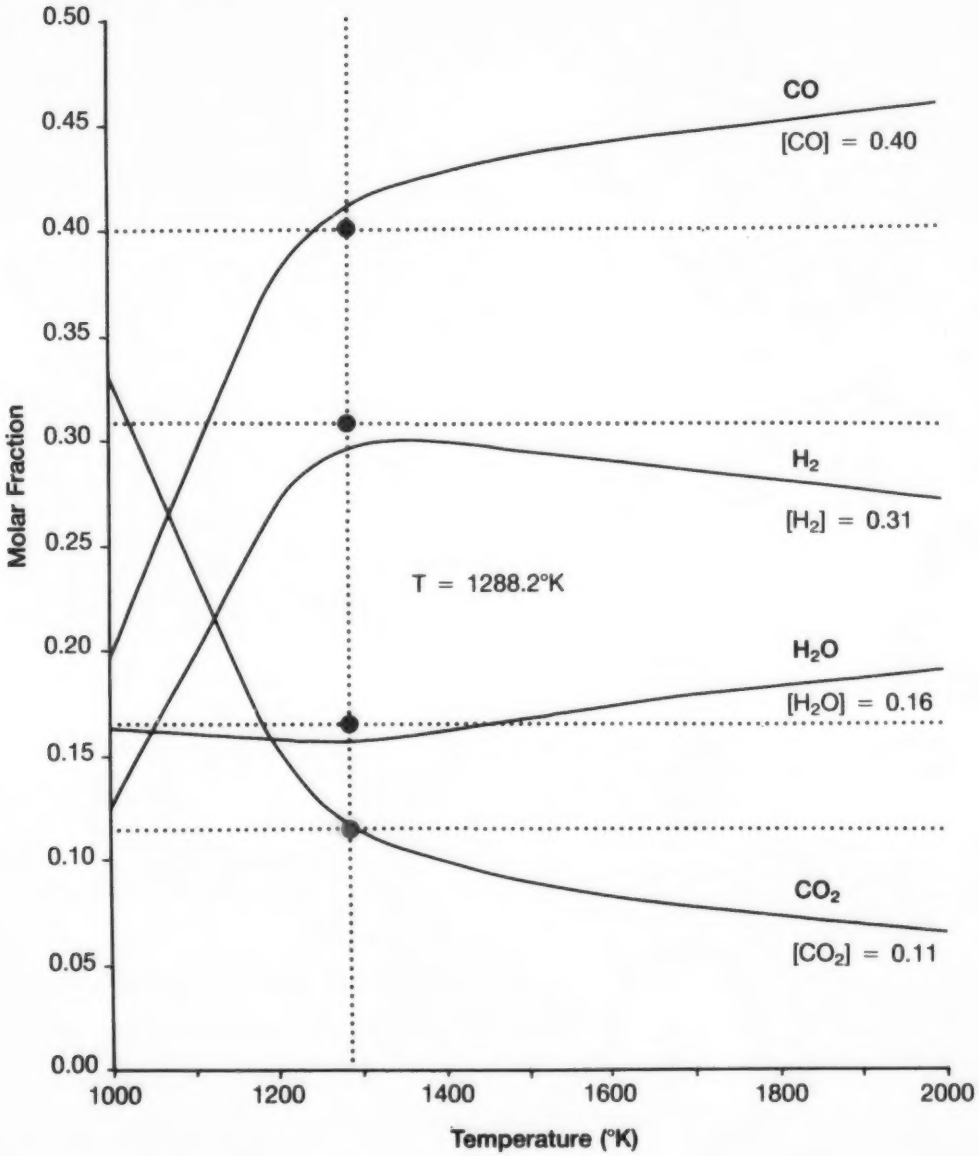
Comparison of Coal Char Reactivities in CO_2 Atmosphere



(Source: *Study of Fundamental Gasification Properties of Alberta Coals*, Kovacik, G., B. Ozum, D. Ungarian and A.K. Chambers, Alberta Research Council, 1988)

The economics of any coal gasification process are influenced greatly by the composition of the product gas. Therefore, Alberta Research Council investigators gained some experience in predicting product gas composition by working with a mathematical model designed for this purpose. The model was used to make calculations based on published data for coals from several sources which had been gasified in the Texaco, PRENFLO and KRW gasifiers. The Facility for the Analysis of Chemical Thermodynamics (F*A*C*T*) software was used in this evaluation.

Predicted Gas Composition for Texaco Gasifier with Pittsburgh #8 Coal.



(Source: *Gasification Characterization of Alberta Coals*, Kovacik, G., B. Ozum and A.K. Chambers, Alberta Research Council, 1988)

Also, calculations of product gas composition and other data from the Cool Water gasification plant in California were used to obtain some experience with computerized simulations of IGCC plants. In this instance, the PROCESS program from Simulation Sciences Inc. was tried.

Fluidized-Bed Gasification of Highvale Coal

In 1987, a consortium of Alberta companies[3], plus CANMET and the Alberta Office of Coal Research and Technology, jointly funded tests of subbituminous coal in a pilot-scale gasification plant. This was a direct result of earlier bench-scale tests which indicated that subbituminous coals are likely to be among the most suitable Alberta coals for gasification. Twenty-five tonnes of coal from the Highvale mine were shipped to Waltz Mill, Pennsylvania and gasified at the KRW Energy Systems facility, the only pilot-scale fluidized-bed gasification plant operating in North America.

Test results indicated that Highvale coal gasified well, with carbon conversion of 89 per cent. A satisfactory sulphur material balance was not achieved, however, because the sulphur content of this coal is very low. Sulphur capture, though, was estimated to be as high as 77 per cent.

Economics of Coal Gasification

An economic analysis of potential gasification applications in Alberta was undertaken in 1987 under the direction of Alberta Power Limited, with additional financial support from TransAlta Utilities Corporation, Esso Resources Canada Limited, Gulf Canada Corporation, Luscar Ltd. and the Alberta Office of Coal Research and Technology. The study was subcontracted to Monenco Consultants Limited. The economics of three options were examined: a 150 MW IGCC plant to produce electricity; a combined 150 MW IGCC plant to produce electricity and a 13 000 kg/h (28 600 lb./hr.) methanol plant; and a 33 000 kg/h (72 600 lb./hr.) plant to produce methanol alone. In all three cases, it was assumed that Highvale subbituminous coal would be the feedstock and a Texaco gasifier would be used.

The consultants used an engineering economics model in the form of a Lotus 1-2-3 spreadsheet. The model was based on published data from the Cool Water demonstration project in the U.S. and from Monenco's experience with utility companies and chemical plants in Alberta.

The analyses revealed that production of electricity alone from coal gas is not economically viable at present, but both co-production of electricity and methanol and production of methanol alone probably are economic.

Corrosion in Gasification Systems

In designing a prototype IGCC plant, engineers must consider materials for construction that can be used in the harsh environment associated with gasification conditions. This is vitally important because equipment failures have been found to occur as a result of shut-down or start-up in gasification plants. The causes of these failures have been categorized as either aqueous corrosion or stress corrosion cracking. Little is known about the mechanisms of these reactions, however.

Consequently, an investigation was undertaken at the University of Calgary to measure the electrochemical properties of several alloys. This was accomplished with a potentiostat. Also, a scanning electron microscope was used to examine the condition of exposed metal surfaces. Eleven alloys were exposed to an aqueous solution containing salts while various gas combinations were passed through the solution. The gases consisted of nitrogen, carbon dioxide, hydrogen sulphide, carbon monoxide, hydrogen, ammonia and methane. Experiments were designed to simulate closely conditions found in pilot-scale gasification plants.

Of all the alloys tested, it was found that Fe-30Mn-8Al exhibited the lowest corrosion rate and showed the least sensitivity to variations in the gasification environment. This alloy outperformed expensive nickel-based materials, as well as other conventional stainless steels. Therefore, it shows considerable promise for use in coal gasification plants and is especially attractive because of its low cost.

[3]Industry participants were: TransAlta Utilities Corporation, Esso Resources Canada Limited, Unocal Canada Limited, Gulf Canada Corporation, Luscar Ltd. and Alberta Power Limited.

Corrosion Behaviour of Materials in Different Gaseous Environments

Material	Corrosion rate, $\mu A/cm^2$					
	CO_2	CO	$32N_2$*	H_2S	U**	NH_3
Mild Steel	11.6	2.4	2.5	2.6	6.8	2.8
Fe-Mn-Al Stainless Steel	1.4	2.3	0.2	1.7	2.5	1.4
316 Stainless Steel	10.6	2.3	1.6	0.4	3.4	0.4
Pyromet 31	1.8	2.3	1.8	1.5	4.0	0.3
Pyromet 751	0.8	3.4	2.1	1.1	4.6	0.7
Hastalloy C22	0.2	5.6	3.8	0.6	5.8	1.1
Hastalloy C276	0.6	4.4	3.4	1.4	5.7	0.7
Custom 450	2.1	6.5	5.1	1.6	5.5	0.8
Ferralium 255	0.6	0.4	1.7	3.2	2.9	0.4
Udimet 700	0.3	5.7	3.9	5.2	5.6	0.6
446 Stainless Steel	0.2	2.8	1.8	0.6	3.9	0.4

(Source: *Aqueous Corrosion of Select Materials in Simulated Coal Gasification Environments*, Jayasinghe, D.M., M.Sc. Thesis, University of Calgary, 1988)

* a mixture of gases containing 32 per cent N_2.

** a mixture of gases, the largest component of which was CO_2.

Among standard alloys, the best performers contained iron plus 20 to 25 per cent chromium and 15 per cent nickel. High nickel contents, however, were found to be detrimental. Also, alloys containing cobalt or molybdenum did not perform well.

The data base resulting from this work should be a useful resource for designers of gasification plants and for materials suppliers involved in developing new materials.

Subsequent Developments

The Canadian Coal Gasification Technical Committee is continuing to support coal gasification research aimed at meeting the objectives listed on page two. Several new projects were launched in 1988 and others are anticipated in mid-1989. Persons interested in participating on this committee should contact:

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Further Reading

Chambers, A.K., B. Ozum and G. Kovacik. 1988. *Staff Training: Gasification Process Research*. Alberta Research Council.

Fluidized Bed Gasification of Highvale Coal. 1988. TransAlta Utilities Corporation.

Jayasinghe, D.M. 1988. *Aqueous Corrosion of Select Materials in Simulated Coal Gasification Environments*. M.Sc. Thesis. The University of Calgary.

Kovacik, G., A.K. Chambers and B. Ozum. 1988. *Gasification Kinetics of Alberta Coals Using a High Pressure Fixed Bed Reactor*. Alberta Research Council.

Kovacik, G., B. Ozum, D. Ungarian and A.K. Chambers. 1988. *Study of Fundamental Gasification Properties of Alberta Coals*. Alberta Research Council.

Kovacik, G., B. Ozum and A.K. Chambers. 1988. *Gasification Characterization of Alberta Coals*. Alberta Research Council.

Kovacik, G. and A.K. Chambers. 1988. *Evaluation of Canadian Coals for Gasification with Texaco, British Gas and Shell Technologies*. Alberta Research Council.

Ozum, B., A.K. Chambers and G. Kovacik. 1988. *Boundary Layer Model for Char Combustion and Gasification*. Alberta Research Council.

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Additional non-confidential information about economic studies of gasification may be available from:

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Other publications in this series which are available and deal with coal research include:

An Economic Analysis of Coal Pipeline Systems,
6 pages, January 1987.

Opportunities to Use Coal in Enhanced Oil Recovery,
8 pages, April 1988.

Development of an Agglomeration Process to Beneficiate and Transport Alberta Coals,
14 pages, June 1988.

Gasification of Western Canadian Coals,
14 pages, June 1988.

Coal Research Centre, Devon,
10 pages, August 1988.

Co-processing Studies of Alberta Subbituminous Coals,
14 pages, December 1988.

Mathematical Modelling of Automedium Cyclones
10 pages, January 1989.

The Technical Committee Approach to Coal Research,
6 pages, January 1989.

Advanced Coal Mining Techniques for Alberta,
10 pages, March 1989.

Some Combustion Studies of Alberta Coals,
13 pages, May 1989.

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